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13. ABSTRACT *(Maximum 200 Words)*

Ten fresh human cadavers were intubated while recording cervical motion using a cinefluoroscopic technique. Segmental cervical motion from the occiput through C5 was measured in both the intact spine and following the creation of a Type II odontoid fracture in all cadavers. Each intubation was performed using no external stabilization, Gardner-Wells traction and manual in-line cervical immobilization. The data are currently being analyzed.

A paper entitled Segmental cervical spine motion during orotracheal intubation of the intact and injured spine with and without external stabilization was published in the *Journal of Neurosurgery*.

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INTRODUCTION

The goal of emergency airway management in patients with suspected cervical injuries is to secure the airway as quickly as possible without worsening the patient's neurologic condition. Current Advanced Trauma Life Support guidelines recommend orotracheal intubation with manual in-line cervical immobilization, although nasotracheal intubation may be considered in the spontaneously breathing patient depending on the skill of the caregiver.[1] There is conflicting evidence whether blind nasotracheal intubation reduces cervical motion[2,6,7,9], and it is less reliable and more time-consuming than the orotracheal approach.[5,10,16,17] This technique is also associated with a substantial incidence of complications, including epistaxis, vomiting, aspiration, and retropharyngeal laceration,[5,8,10,23] and is best performed in cooperative patients.

The data documenting the efficacy of any method in reducing cervical movement during intubation are limited. Most published studies focus on movement of the intact spine, but very little work has been done on motion of the unstable cervical spine during intubation.[15] Although a few reports have focused on the motion of a single unstable level[3,6,7] no previous investigation has quantified segmental motion during intubation of the injured cervical spine and the effect of commonly used stabilization procedures on that motion.

Our group has previously demonstrated that in living patients with intact cervical spines the majority of motion occurs at the craniovertebral junction, followed by the atlantoaxial junction, with only a minor contribution from the subaxial spine.[20] Our early work did not address the effects of stabilization or instability on cervical motion during intubation. Given the minimal contribution of the subaxial cervical spine to the motion of intubation in the normal condition, the question arises as to what effect increased subaxial instability has on overall motion and how do stabilization maneuvers limit this motion.

BODY

We had proposed testing our hypotheses by performing 6 specific projects, two in each year of the study.

In the 1997-98 year we examined cervical motion during orotracheal intubation in cadavers without and with traction, immobilization, and a hard cervical collar. Although we had anticipated studying only 6 cadavers, we were able to obtain data from 16. Cervical motion was evaluated during orotracheal intubation in cadavers before and after creation of a significant posterior ligamentous disruption.

In the 1998-99 year we examined cervical motion during orotracheal intubation in cadavers without and with traction, immobilization, and a hard cervical collar. Although we had anticipated studying only 6 cadavers, we were able to obtain data from 10. Cervical motion was evaluated during orotracheal intubation in cadavers before and after creation of a significant posterior ligamentous disruption.

In the 1999-2000 year we examined cervical motion during orotracheal intubation in cadavers without and with traction, immobilization, and a hard cervical collar before and after the creation an odontoid fracture.

We also evaluated cervical motion during orotracheal intubation in patients without and with cervical traction. We were unable to accrue patients for an intubation study with and without hand-held immobilization and a rigid cervical orthosis.

CADAVER STUDIES

General Experimental Methods

All subjects had intact cervical spines and were evaluated under fluoroscopy and found to have a normal range of motion prior to intubation. Each subject was placed supine on a flat surface and a routine direct laryngoscopy and orotracheal intubation was performed in all cases using a #3 Macintosh blade and a wire-reinforced endotracheal tube. Exposure of the glottis was limited to that necessary to allow passage of the endotracheal tube through the vocal cords under direct visualization. The same procedure was used for each method of stabilization in the intact as well as the posterior ligament-disrupted subjects. Minimal visualization was intentional to produce minimal cervical movement as would be done in a trauma situation. All intubations were performed by an experienced faculty anesthesiologist.

Procedure

Each subject was intubated serially while applying no external stabilization, manual in-line cervical immobilization then traction. A neurosurgeon performed all stabilization maneuvers for all intubations. For traction, Gardner-Wells tongs were placed and force was exerted throughout the intubation procedure by hand until the neurosurgeon felt that it was a proper amount based on clinical experience. Force was measured with a spring-gauge scale and ranged from 7-10 pounds. For in-line cervical immobilization, the head was manually stabilized by grasping the mastoid processes bilaterally to limit movement throughout the intubation sequence without application of traction.

In all cases, the entire laryngoscopy and intubation sequence was monitored and recorded with continuous lateral fluoroscopy of the cervical spine. The occipital base through C5 was visualized and the head maintained contact with the table at all times throughout the sequence. Cervical segments caudal to C5 could not be consistently visualized due to the shoulders. Fluoroscopic images were recorded on a VHS-formatted video recorder interfaced with the fluoroscopy machine.

Data Processing

Video images were digitized using a frame grabber, either IP Lab Spectrum version 2.3.1e (Signal Analysis, Vienna, Virginia) or Flashpoint version 4.0 (Integral Technologies, Indianapolis, Indiana). The digitized 640x480 grayscale images were analyzed using freely available image analysis software. On a Macintosh computer, NIH Image 1.55 or 1.61 was used (The National Institutes of Health, Bethesda, MD available over the internet by anonymous FTP from ftp://zippy.nimh.nih.gov/pub/nih-image). On a PC-compatible, UTHSCSA ImageTool 1.27 was

used (developed at the University of Texas Health Science Center at San Antonio, Texas and available over the internet by anonymous FTP from ftp://maxrad6.uthscsa.edu).

Each intubation sequence was digitized at five distinct stages: (1) **Baseline** denoted by the head and neck in neutral position prior to any manipulation or insertion of the laryngoscope, (2) **L1** at first appearance of the laryngoscope in the glottis, (3) **L2** after the laryngoscope was advanced into the vallecula and a ventral lifting force was applied to its maximal excursion prior to passage of the endotracheal tube, (4) **Tube** when the endotracheal tube passed through the vocal cords, and (5) **Post** after the laryngoscope was removed and the head and neck came to their final resting positions.

Segmental anterior-posterior translation was always less than 1 mm; thus, angular changes were used to compare subjects. The angular position of each segment, occiput through C5, was measured at the five stages of the intubation sequence. Two reproducible bony reference points were chosen for each segment that remained constant for that intubation sequence. The line created by intersecting each set of reference points was then referenced to either the horizon or vertical, depending on its absolute position in space, such that forward rotation of the segment would increase the angular measurement and backward rotation would decrease the angular measurement. The horizontal/vertical line remained constant during that intubation sequence. Reproducibility with this technique is very good as previously published[20] with an average intraobserver variability of 0.37° and an average interobserver variability of 0.48°.

Angular values were referenced to baseline and these changes from baseline were used for comparison. Our cervical motion data, as well as that of two other publications,[9,12] were not distributed normally. Thus, nonparametric Wilcoxon signed-rank test was used to determine significant paired-differences between angular measurements. The intact series without stabilization was compared to previously published live patient data at each stage and level. To assess motion independent of direction, the absolute value of the greatest angular movement for each cervical level during the intubation sequence was used for comparison. Thus, for example, two degrees of flexion would not be considered different from two degrees of extension as this represents a change in the direction of movement without a change in the amount of movement. A probability value of less than 0.05 was considered significant.

Specific Experimental Methods

Partial Instabiliity

Sixteen fresh human cadaveric subjects, including seven males and nine females ranging in age from 50 to 89 years, were used for this study. Movement of the intact spine during orotracheal intubation is characterized mainly by extension at all levels during all stages except minor flexion at some levels during L1. Of the sixteen subjects, five were only stabilized with traction and not manual immobilization. Eleven subjects were stabilized by both methods.

After completion of the intact cervical intubation series, each subject was placed in a prone position and a midline cervical incision was made. The C4-5 level was identified with

fluoroscopy and the supraspinous, interspinous, facet ligaments, posterior longitudinal ligament and ligamentum flavum were incised with a scalpel blade. The facets were bilaterally dislocated following the ligamentous disruption to verify the degree of instability. The facets were then reduced. The wound was closed following destabilization. The previously describe sequence of intubations was repeated.

Complete Instability

After completion of the intact cervical intubation series, each subject was placed in a prone position and a midline cervical incision was made. The C4-5 level was identified with fluoroscopy and the supraspinous, interspinous, facet ligaments, posterior longitudinal ligament and ligamentum flavum were incised with a scalpel blade. An osteotome was then used to cut the anterior and posterior annulus, disc and the anterior longitudinal ligament. The facets were bilaterally dislocated following the ligamentous disruption and then repostioned in the normal alignment. The wound was closed following destabilization. The subject was returned to the supine position. Dynamic fluoroscopic examination verified a complete segmental injury and a high degree of instability. The previously describe sequence of intubations was repeated.

Odontoid Fracture

After completion of the intact cervical intubation series the base of the dens was fractured using an osteotome. The lesion created was radiographically identical to a type II odontoid fracture. Dynamic fluoroscopic examination verified the instability of the lesion. The previously described sequence of intubations was repeated.

Results

Partial Instabiliity

The greatest motion occurred at the craniovertebral junction, followed by the atlantoaxial junction. Motion decreased sequentially at each more caudal interspace. The greatest movement occurred during the L2 and Tube stages (Fig. 1). These results are statistically indistinguishable from the results in living subjects.[20]

During orotracheal intubation, the injured spine experienced the greatest motion at the craniovertebral junction followed by the atlantoaxial junction. The predominant motion was extension at all levels except at the destabilized C4-5, where intubation caused flexion (Figs. 2, 3) instead of the extension produced in the intact spine.

Traction significantly reduced craniovertebral junction motion in both the intact as well as the injured spines. In the intact spine (Table 1), craniovertebral junction motion decreased from 8.8°to 4.9° ($P<0.05$). In the injured spine (Table 2), motion decreased from 7.3° to 5.3° ($P<0.05$). Traction did not significantly reduce motion at any other level. Manual in-line cervical immobilization did not significantly limit motion at any level during intubation.

There was a trend toward decreased C4-5 motion with both forms of stabilization in the intact spine (Table 1) and increased motion with both forms of stabilization in the injured spine (Table 2), although these differences were not statistically significant.

Complete Instability

A detailed analysis of antero-posterior (AP) subluxation and distraction at the level of injury has been performed.

The median distraction for each stage of intubation for no traction, traction, and immobilization are depicted in Figure 4. No increase in distraction occurred throughout the standard intubation sequence. It is interesting to note that following a standard intubation (post phase) there was less distraction than before the sequence began (baseline). Immobilization effectively prevented distraction from occurring at all phases of intubation including the post intubation period. Distraction did occur with the application of traction. This was most severe during the tube phase of intubation. The median distraction at this point was over 1.6 mm.

Figure 5 shows a comparison of the maximum distractions resulting from intubation while applying no traction, traction and immobilization. Application of no traction during intubation resulted in reduced distraction whereas application of traction resulted in a median distraction of 1.1 mm. Immobilization resulted in a median distraction of 0 mm. The data were assessed using the nonparametric Wilcoxon signed-rank test. Maximum Distraction was significantly increased during intubation under traction as compared to intubation without traction ($p= 0.03$).

The median subluxation for each stage of intubation for no traction, traction, and immobilization are depicted in Figure 6. Both intubation without traction and while immobilizing the cadavers head resulted in anterolisthesis of C4 on C5 which was maximal during the tube phase. The median anterolisthesis during the tube phase with immobilization was 1.9 mm compared to 1.0 mm with no traction and 0 mm with traction. This anterolisthesis reduced to baseline in the post phase with no traction, but not with immobilization. Traction effectively prevented subluxation from occurring at all phases of intubation including the post intubation period.

Figure 7 shows a comparison of the maximum subluxations resulting from intubation while applying no traction, traction and immobilization. Application of no traction during intubation resulted in a median anterior subluxation of C4 on C5 of 1.0 mm whereas immobilization resulted in a median subluxation of 1.9 mm. Traction resulted in a median distraction of 0 mm.

Odontoid Fracture

The data from the Type II odontoid fractures is complex. Similar to the completely destabilized subaxial segments, there was motion in both the sagittal plane and significant distraction in some conditions. We are in the process of analyzing the data more completely

PATIENT STUDY

Experimental Methods

Nine human subjects were studied. The preoperative clinical exam included a detailed spinal history and examination. The demographics of these patients and the airway assessment are shown in Table 3. Although some patients were undergoing surgery for cervical disc disease, the upper cervical spine (occiput to axis) and the subaxial spine to C5 were clinically and radiographically normal. Motion in flexion and extension was radiographically within the normal range. The airway of each subject was assessed using the Malampati system.[19]

Each patient was given a general anesthetic and ventilation maintained with a mask. Gardner-Wells tongs were applied in the usual fashion. A standard intubation with a MacIntosh blade was performed without traction. Following this intubation the endotracheal tube was removed and ventilation was again achieved by masking. In-line traction was administered manually using Gardner-Wells tongs by the principal investigator. This was done by pulling on a spring gauge which was attached to the tongs. The amount of traction delivered was determined by the principal investigator and based entirely on clinical judgement. An observer noted the reading on the spring gauge which was consistently in the range of 10-12 pounds. The patient was intubated while the traction was applied. The ease of intubation was assessed by the anesthesiologist. The optimal airway view was scored according to Cormack.[4] The Malampati Grade, ease or difficulty of intubation, and Cormack scores for each patient are listed in Table 4.

All intubations were performed under continuous fluoroscopic monitoring. The fluoroscopic images were recorded on a VHS-formatted video recorder interfaced with the fluoroscopy machine and digitized as previously described. There was less than 1 mm of anteroposterior translation at each motion segment. The segmental angular motion was determined as previously described.

Results

Cervical segmental relationships were calculated as intervertebral angles (IVA) at baseline and four points during the procedure. IVA changes were measured in degrees, with extension assigned positive values. To document extreme effects of intubation, maximal IVA changes were reported. These measurements, before and after traction were 26.6 and 17.7 degrees at O-Cl, 11.1 and 8.5 at Cl-C2, 4.8 and 7.0 at C2-C3, 9.1 and 7.3 at C3-C4, and 8.5 and 7.8 at C4-C5. Median values were 10.6 and 5.2 degrees at O-Cl, 5.4 and 1.9 at Cl-C2, 1.7 and 1.4 at C2-C3, 2.7 and 1.8 at C3-C4, and 1.5 and 2.2 at C4-C5. While this limitation of motion was very statistically significant at the atlanto-occipital and atlanto-axial junctions, this was not true more caudally. The clinical impact of this reduced cervical motion, however, is unknown. Further evaluation of cervical motion during intubation in patients with abnormalities is warranted.

The motion data are graphically displayed in Figures 8 and 9. The motion of the cervical spine during intubation without traction was similar to that described earlier in this report and in our previous publication.[20] Hand-held traction altered the motion characteristics of the cervical spine during intubation as compared to the freely mobile spine. Specifically, motion across the O-C1 segment decreased by about 2° at the L2 and Tube phases. Motion at the C1-C2 level during these phases decreased 4° and 3°, respectively. The greatest change occurred at the C2-C3 segment where almost no motion occurred throughout the entire intubation process. There was a slight decrease in motion at C3-C4 during the tube phase only. There was little motion detected at C4-C5 accounting for about a 2° difference in most phases of intubation as compared to the nontraction condition. Overall, the effect of traction on cervical spinal motion during intubation in live patients was almost identical to that noted in our cadaveric study.

LEGENDS

Figure 1 Graph comparing median values of motion experienced during each stage of cadaveric intubation for levels O-C1 through C4-5. Positive numbers represent degrees of extension and negative numbers degrees of flexion.

Figure 2 Graph comparing median values of greatest motion experienced during the cadaveric intubation sequence for levels O-C1 through C4-5 with no stabilization, traction and immobilization in the intact spine. Positive numbers represent degrees of extension and negative numbers degrees of flexion.

Figure 3 Graph comparing median values of greatest motion experienced during the intubation sequence for levels O-C1 through C4-5 with no stabilization, traction and immobilization in the injured spine with a destabilized C4-5 segment. Positive numbers represent degrees of extension and negative numbers degrees of flexion.

Figure 4 Graph comparing median distraction at each stage of intubation for different methods of stabilization.

Figure 5 Bar graph comparing median maximum distraction at the injured C4-C5 segment during intubation for different methods of stabilization.

Figure 6 Graph comparing antero-posterior translation at each stage of intubation for different methods of stabilization.

Figure 7 Bar graph comparing the maximum antero-posterior translation for different methods of stabilization.

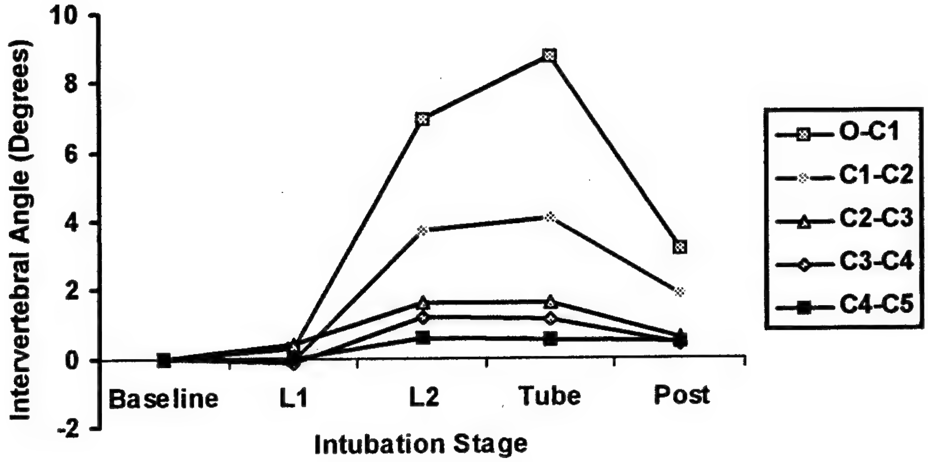
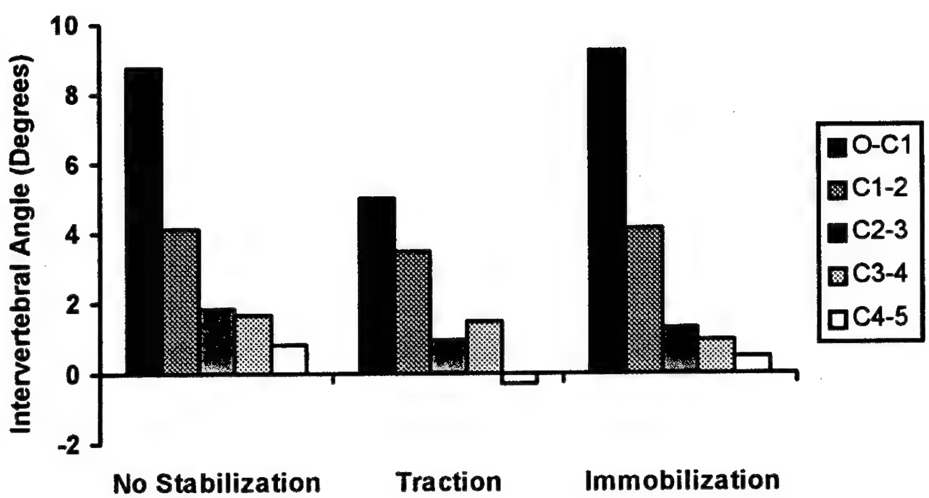


Figure 1



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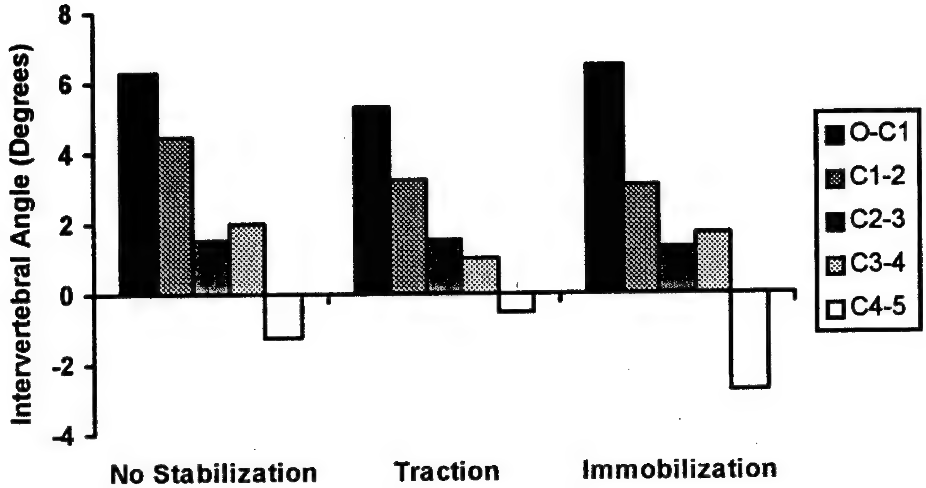


Figure 3

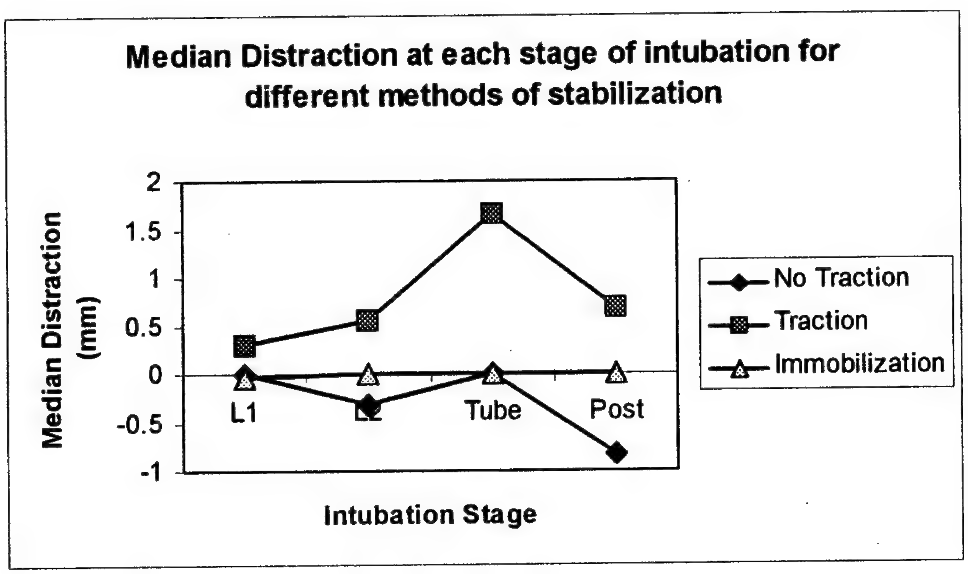
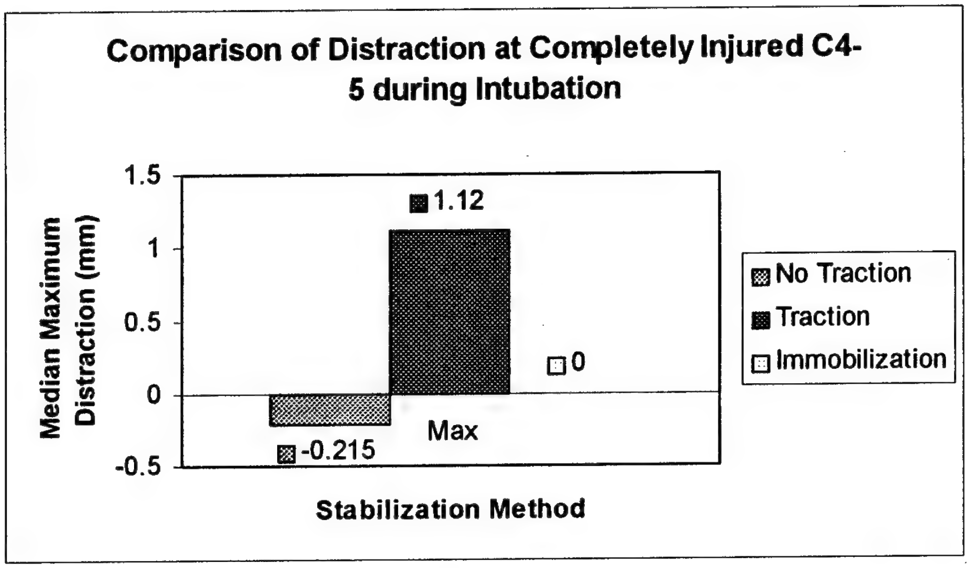


Figure 4



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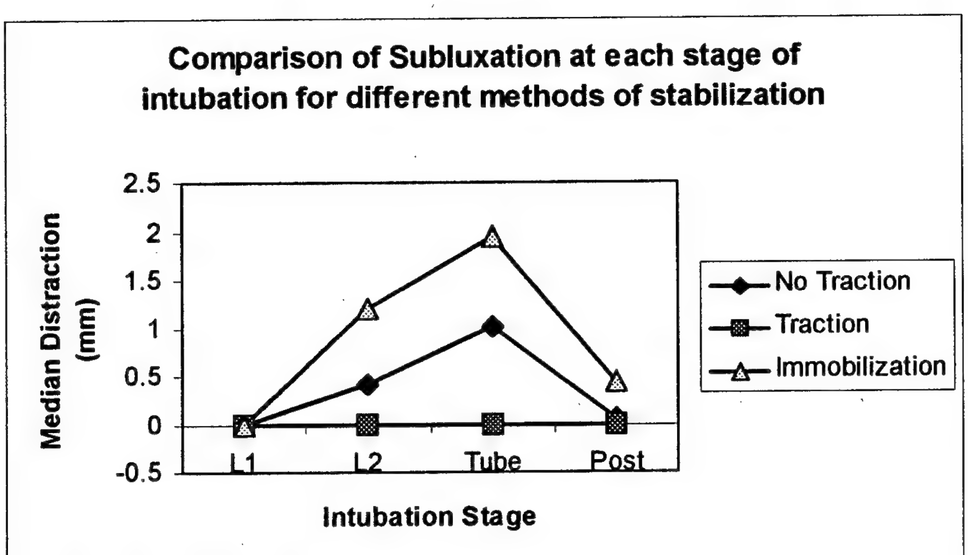

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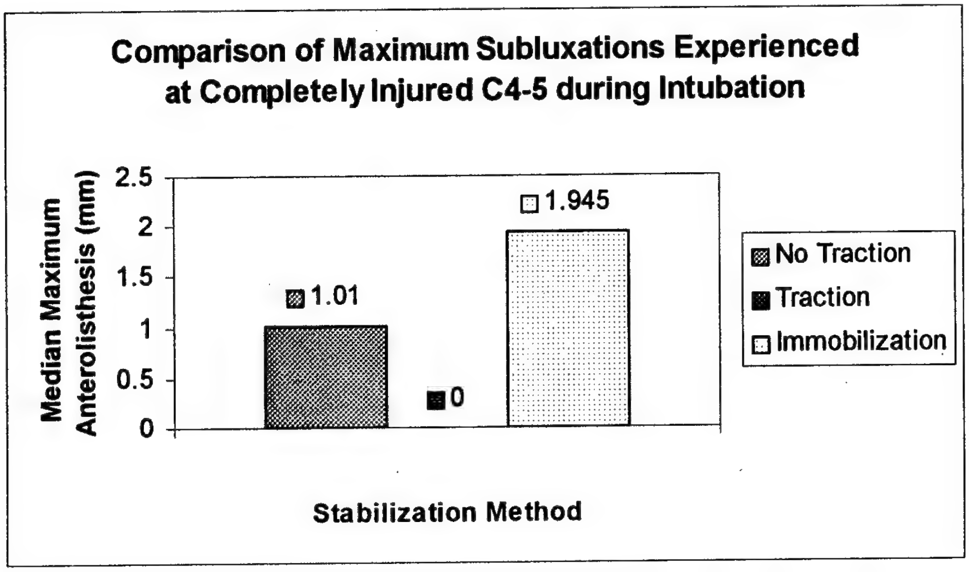

Figure 7

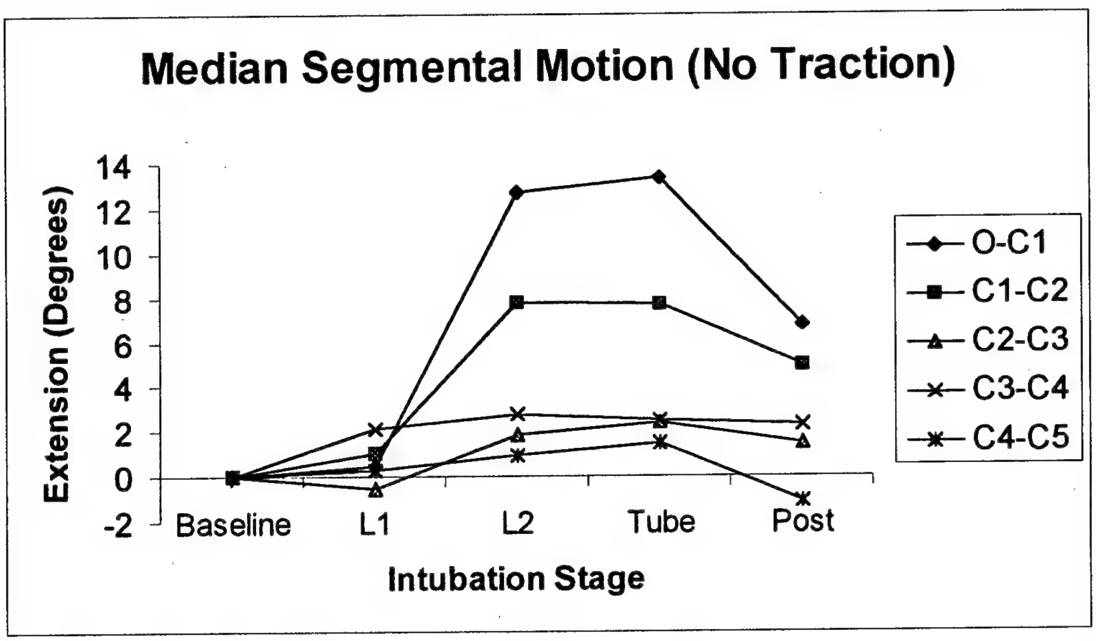

Figure 8

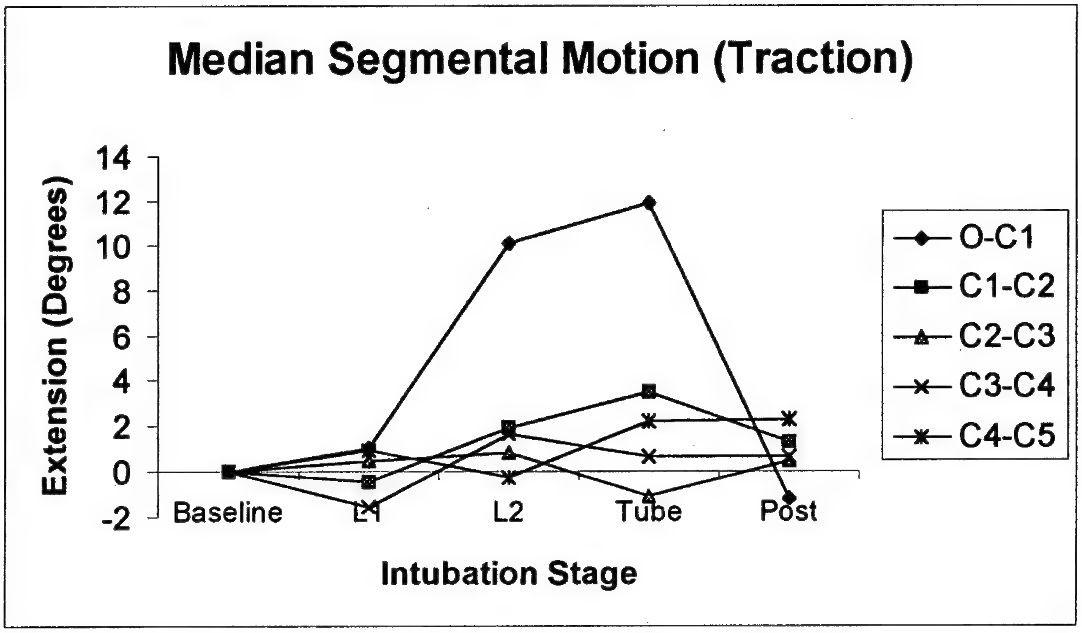
Median Segmental Motion (Traction)
Extension (Degrees)
14
12
10
8
6
4
2
0
-2
Baseline
L1
L2
Tube
Post
Intubation Stage
O-C1
C1-C2
C2-C3
C3-C4
C4-C5

Figure 9

Table 1	Median values of absolute greatest angular motion (degrees) in the intact spine at levels O-C1 through C4-5 with no stabilization, traction and immobilization. Statistically significant values are indicated in bold.
Table 2	Median values of absolute greatest angular motion (degrees) in the injured spine at levels O-C1 through C4-5 with no stabilization, traction and immobilization. Statistically significant values are indicated in bold.
Table 3	Subject Demographics
Table 4	Malampati and Cormack scores for individual patients and specific events.
Table 5	Median and Maximal motion (degrees) at each level during intubation of patients without and with hand held traction. Marked values are statistically significant (Paired nonparametric Wilcoxon signed rank test, two tailed, $p< 0.05$)

TABLE 1

Level	No Traction	Traction	Immobilization
O-C1	**8.8**	**4.9**	9.3
C1-2	4.1	3.5	4.1
C2-3	1.8	1.7	2.2
C3-4	1.9	1.9	2.4
C4-5	2.1	1.2	1.9

TABLE 2

Level	No Traction	Traction	Immobilization
O-C1	**7.3**	**5.3**	6.8
C1-2	4.5	3.3	3.1
C2-3	1.6	1.7	1.7
C3-4	2.0	1.6	1.7
C4-5	1.8	2.2	2.8

TABLE 3

Subject Number	Sex	Age (years)	Height (feet)	Weight (pounds)
1	Female	46	5.5	187
2	Male	59	5.7	185
3	Male	45	5.5	200
4	Male	50	5.8	285
5	Male	47	5.8	174
6	Male	74	5.5	140
7	Female	39	5.4	174
8	Male	55	5.8	185
9	Female	57	5.5	185

TABLE 4

Subject Number	Malampati	Mask Ventilation	1st Laryngoscopy, view (Cormack)	2nd Laryngoscopy, view (Cormack)
1	I	easy	easy, I	easy, II
2	I	easy	easy, II	easy, II
3	II	easy	easy, I	difficult, III
4	I	easy	easy, I	easy, I
5	I	easy	easy, II	easy, II
6	II	easy	easy, II	easy, II
7	II	easy	easy, II	moderate, III
8	I	moderate	moderate, III	moderate, II
9	II	easy	easy, II	easy, I

TABLE 5

LEVEL	NO TRACTION		TRACTION	
	MEDIAN	MAXIMAL	MEDIAN	MAXIMAL
O-C1	10.6*	26.6	5.2*	17.7
C1-2	5.4*	11.1	1.9*	8.5
C2-3	1.7	4.8	1.4	7.0
C3-4	2.7	9.1	1.8	7.3
C4-5	1.5	8.5	2.2	7.8

* Indicates a statistically significant change ($p<0.05$).

KEY RESEARCH ACCOMPLISHMENTS

1. Validity of motion data from cadaveric studies validated with human studies and published.
2. Cadaveric cervical motion during intubation detailed in cadavers and published.
3. Cadaveric cervical motion during intubation with hand-held immobilization, traction, and a cervical orthosis determined, analyzed, and published.
4. Cadaveric cervical motion during intubation in the presence of a partial subaxial ligamentous injury with and without hand-held immobilization, traction, and a cervical orthosis determined, analyzed, and published.
5. Cadaveric cervical motion during intubation in the presence of a complete segmental subaxial injury with and without hand-held immobilization, traction, and a cervical orthosis determined and analyzed.
6. Cadaveric cervical motion during intubation in the presence of a Type II odontoid fracture with and without hand-held immobilization, traction, and a cervical orthosis determined.
7. Human cervical motion during intubation with and without traction determined and analyzed.

REPORTABLE OUTCOMES

All of the key research accomplishments are reportable. Some of these have already been published.

CONCLUSIONS

Cervical motion measured in fresh cadavers during orotracheal intubation accurately reflects that of living patients. Little motion occurs at C4-5 during direct laryngoscopy and orotracheal intubation in either the intact or posteriorly injured states, and neither manual in-line cervical immobilization nor traction has a significant effect on motion at C4-5 under these conditions. However, since the extent of injury is often unclear, especially in an emergent situation, it is still recommended that an attempt at stabilization be considered.

In a completely destabilized C4-5 segment, traction effectively eliminates subluxation, but results in increased distraction. Immobilization effectively eliminates distraction, but results in increased subluxation. Application of no traction or immobilization has intermediate results with more subluxation than traction, and less restriction of longitudinal motion than immobilization (although the motion that occurs is a reduction in the space between C4 and C5).

Traction significantly decreased both the median and maximum segmental angular motion at O-C1 and C1-C2. The clinical impact of this reduced cervical motion is unknown. Traction did not limit motion in the sub-axial spine, however, very little motion occurred at these levels even without traction. Further evaluation of cervical motion during intubation in patients with abnormalities is warranted.

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APPENDICES

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Lennarson PJ, Smith D, Todd MM, Carras D, Sawin PD, Brayton J, Sato Y, Traynelis VC: Segmental cervical spine motion during orotracheal intubation of the intact and injured spine with and without external immobilization. J Neurosurg (Spine 2) 92:201-206, 2000

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Segmental cervical spine motion during orotracheal intubation of the intact and injured spine with and without external stabilization

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Object. The purpose of this study was to establish a cadaveric model for evaluating cervical spine motion in both the intact and injured states and to examine the efficacy of commonly used stabilization techniques in limiting that motion.

Methods. Intubation was performed in fresh human cadavers with intact cervical spines, following the creation of a C4–5 posterior ligamentous injury. Movement of the cervical spine during direct laryngoscopy and intubation was recorded using video fluoroscopy and examined under the following conditions: 1) without external stabilization; 2) with manual in-line cervical immobilization; and 3) with Gardner–Wells traction. Subsequently, segmental motion of the occiput through C-5 (Oc–C5) was measured from digitized frames of the recorded video fluoroscopy.

The predominant motion, at all levels measured in the intact spine, was extension. The greatest degree of motion occurred at the atlantooccipital (Oc–C1) junction, followed by the C1–2 junction, with progressively less motion at each more caudal level. After posterior destabilization was induced, the predominant direction of motion at C4–5 changed from extension to flexion, but the degree of motion remained among the least of all levels measured. Traction limited but did not prevent motion at the Oc–C1 junction, but neither traction nor immobilization limited motion at the destabilized C4–5 level.

Conclusions. Cadaveric cervical spine motion accurately reflected previously reported motion in living, anesthetized patients. Traction was the most effective method of reducing motion at the occipitocervical junction, but none of the interventions significantly reduced movement at the subaxial site of injury. These findings should be considered when treating injured patients requiring orotracheal intubation.

Key Words • **laryngoscopy** • **orotracheal intubation** • **cervical spine** • **manual in-line immobilization** • **traction** • **injury**

The goal of emergency airway management in patients with suspected cervical spine injuries is to secure the airway quickly without worsening the patient's neurological condition. Current Advanced Trauma Life Support guidelines recommend orotracheal intubation with manual in-line cervical spine immobilization. Nasotracheal intubation may be considered in the spontaneously breathing patient, depending on the skill of the caregiver.[1] There is conflicting evidence as to whether blind nasotracheal intubation reduces cervical motion,[2,5,6,8] but most authors agree that it is less reliable and more time-consuming than the orotracheal approach.[4,9,12,13] This technique is associated with a substantial incidence of complications, including epistaxis, vomiting, aspiration, and retropharyngeal laceration,[4,7,12,16] and is best performed in cooperative patients.

The data documenting the efficacy of any method in reducing cervical movement during intubation are extremely limited. Most published studies focus on movement of the intact spine,[8,10,11] but very little work has been conducted on determining motion of the unstable cervical spine during intubation. Although the authors of a few reports have examined the motion of a single unstable level,[3,5,6] no previous investigation has quantified segmental motion of the injured cervical spine during intubation or the effect of commonly used stabilization procedures on that motion.

It has been previously demonstrated that the majority of motion during direct laryngoscopy and orotracheal intubation in anesthetized, paralyzed patients with intact cervical spines occurs at the Oc–C1 junction, which is followed in frequency by the C1–2 junction, with only a minor contribution from the subaxial spine.[15] The effects of stabilization maneuvers or instability on cervical spinal motion during intubation were not addressed in this study.

Abbreviations used in this paper: Oc = occiput; Oc–C1 junction = atlantooccipital junction.

Given the minimum contribution of the subaxial cervical spine to the motion of intubation in the normal condition, the question arises as to what effect subaxial instability has on overall motion and how efficacious stabilization maneuvers are in limiting this motion.

The purpose of this study is threefold: 1) to analyze cervical motion in cadavers with intact cervical spines during direct laryngoscopy and orotracheal intubation and to compare the results with those of living patients by using the same video fluoroscopy technique; 2) to characterize and compare segmental cervical movement during orotracheal intubation in cadavers with and without a subaxial posterior ligamentous injury; and 3) to evaluate the ability of manual in-line cervical immobilization and traction to limit cervical motion during intubation in the intact and injured states.

Materials and Methods

Fresh Cadavers

Sixteen fresh human cadavers, including seven males and nine females ranging in age at the time of death from 50 to 89 years, were used for this study. All cadavers had intact cervical spines, underwent fluoroscopic evaluation, and were found to have a normal range of motion before intubation.

Intubation Procedure

Each cadaver was placed supine on a flat surface with an 8- to 10-cm foam pad under the occiput. Routine direct laryngoscopy and orotracheal intubation were performed in all cases by using a No. 3 Macintosh blade and a wire-reinforced (to facilitate radiographic visualization) 7.- or 7.5-mm internal diameter endotracheal tube. Exposure of the glottis was limited to that necessary to allow passage of the endotracheal tube through the vocal cords under direct visualization. This limited visualization was intended to produce the least cervical movement possible, as would be done in a trauma situation. The same procedure was used for each method of stabilization in the intact, as well as the destabilized, cases. All intubation procedures were performed by an experienced faculty anesthesiologist (D.C.).

Stabilization Procedure

Each cadaver was intubated serially under the following conditions: with the provision of no external stabilization, while performing manual in-line cervical immobilization, and during the application of axial traction. A neurosurgeon performed each stabilization maneuver for all intubations. For in-line cervical immobilization, the head was manually stabilized by grasping the mastoid processes bilaterally with the fingertips while cupping the occiput in the hands. No traction was applied with this technique. For traction, Gardner–Wells tongs were applied, and manual force was exerted throughout the intubation procedure. The amount of force was determined by the neurosurgeon based on clinical experience and was monitored by manual feedback. Additionally, the force was measured with a spring-gauge scale and ranged from 7 lbs. to 10 pounds. Of the 16 cadavers, the first five were stabilized using only traction and not manual immobilization. The remaining 11 cadavers were stabilized by using both methods.

Creation of Injury

After completion of the intact cervical intubation series, each cadaver was placed in a prone position, and a midline cervical incision was made. The C4–5 level was identified using fluoroscopy, and the supraspinous, interspinous, facet ligaments, posterior longitudinal ligament, and ligamentum flavum were incised with a scalpel. The facets were bilaterally dislocated following the ligamentous disruption to verify the degree of instability. The facets were then reduced. The wound was closed and the body was returned to the supine position.

Data Acquisition

In all cases, the entire laryngoscopy and intubation sequence was recorded using continuous cross-table fluoroscopy of the cervical spine. The occipital base through C-5 was visualized, and the head remained in contact with the occipital pad at all times throughout the sequence. Cervical segments caudal to C-5 could not be consistently visualized due to interference from the shoulders. Fluoroscopic images were recorded on a VHS-formatted video recorder interfaced with the fluoroscopy machine.

Data Processing

Video images were digitized using a "frame grabber," either an IP Lab Spectrum version 2.3.1e (Signal Analysis, Vienna, VA) or a Flashpoint version 4.0 (Integral Technologies, Indianapolis, IN). The digitized 640 × 480–grayscale images were analyzed using freely available image analysis software. On a Macintosh computer, NIH Image 1.55 or 1.61 was used (National Institutes of Health, Bethesda, MD; available over the Internet by anonymous FTP from ftp://zippy.nimh.nih.gov/pub/nih-image). On a PC-compatible computer, UTHSCSA ImageTool 1.27 was used (University of Texas Health Science Center, San Antonio, TX; available over the Internet by anonymous FTP from ftp://maxrad6.uthscsa.edu).

Each intubation sequence was digitized at five distinct stages: baseline, L1, L2, tube, and post. Baseline was defined as the time when the head and neck were in neutral position before insertion of the laryngoscope; L1, the first appearance of the laryngoscope in the posterior pharynx; L2, that moment when the laryngoscope was advanced into the vallecula and a ventral lifting force was applied to its maximal excursion, but before passage of the endotracheal tube; tube, the instant when the endotracheal tube was passed through the vocal cords; and post, the period after the laryngoscope was removed and the head and neck were returned to their resting position.

In both the intact and the partially destabilized states, anterior–posterior translation remained less than 1 mm; therefore, only sagittal intervertebral angular motion was used to compare subjects. The angular position of each segment, Oc–C5, was measured at the five stages of the intubation sequence (Fig. 1). Two reproducible bony reference points were chosen for each segment, and these remained constant throughout this portion of the intubation sequence. The line created by intersecting each set of reference points was then referenced to either a horizontal or vertical line, such that forward rotation consistently produced a negative angular change (Fig. 1). The horizontal/vertical line remained constant throughout that stage of the intubation sequence. The angular rotational value obtained for each segment, Oc–C5, for every stage (L1 through post) was then related to its angular value obtained at the baseline stage to give an angular change from baseline. Angular changes from baseline for adjacent vertebral levels were combined mathematically to calculate intervertebral angular changes from baseline (Oc–C1 through C4–5) for each stage of intubation. Consistent with our previous publication, extension values were denoted by positive numbers and flexion values by negative numbers.

Statistical Analysis

The population median was used to evaluate changes in direction of motion. The absolute value of angular motion was used for statistical comparisons to examine the amount of motion independent of the direction of motion. Thus, for example, 2° of flexion would represent a change in the direction of motion from 2° of extension, though not a change in the amount of motion. Our cervical motion data, as well as that of two other studies,[8,10] were not distributed normally; consequently, the nonparametric Wilcoxon signed-rank test was used to determine significant paired differences between angular measurements.

First, the intact cadaveric series in which no stabilization measures were taken was compared with previously published data obtained in living patients at each stage and level. Subsequently, motion during manual in-line cervical immobilization and traction was compared with that in which stabilization was not provided, for both the intact and injured cadaver series. Degrees of rotatory motion were converted to radians for the purpose of statistical analysis. A probability value of less than 0.05 was considered significant.

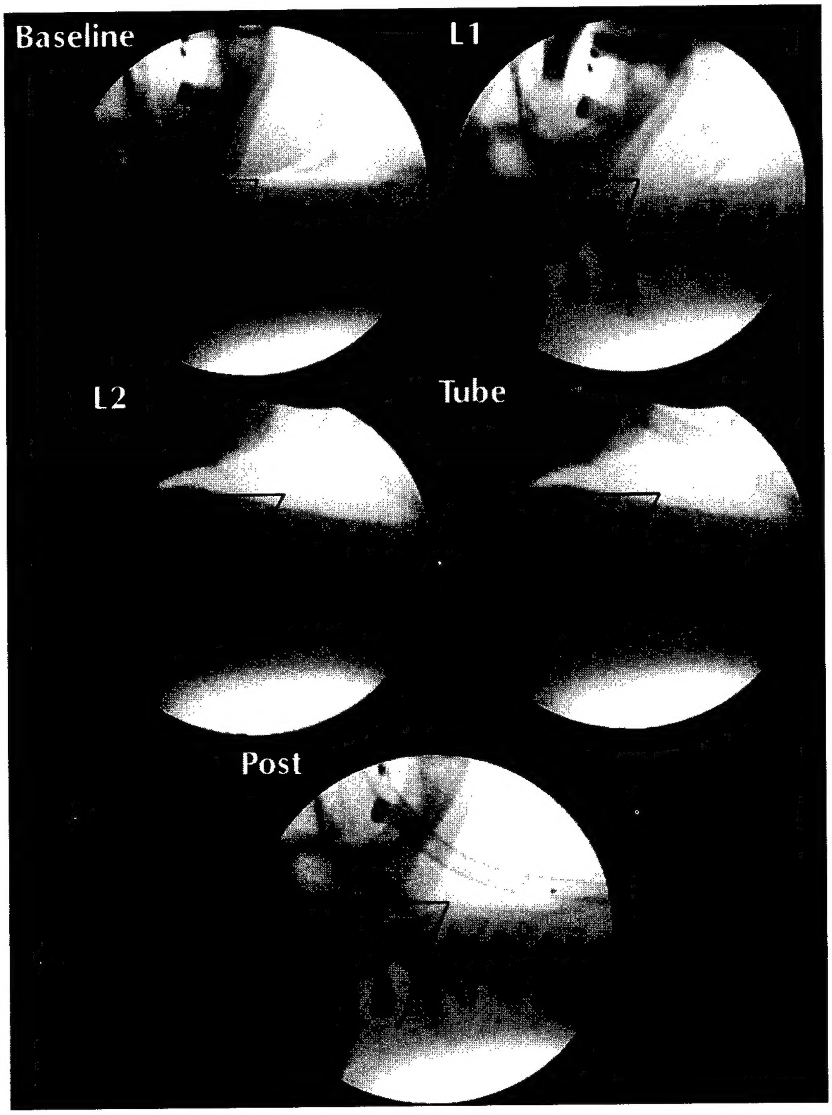

FIG. 1. Digitized frames of video fluoroscopy obtained for each of the five stages of intubation. Overlying lines represent angular positions of C-2 referenced to the horizon (definition of stages found in *Data Processing*).

Results

Motion of the Intact Cadaveric Cervical Spine

During direct laryngoscopy and orotracheal intubation, extension was the predominant direction of motion at all measured levels (Oc–C5) during all stages except for some minimal flexion at some levels during the L1 stage. The greatest degree of motion occurred at the Oc–C1 junction, which was followed by the degree of motion at the C1–2 segment, and motion decreased sequentially at each more caudal interspace. The greatest motion occurred during the L2 and tube stages (Fig. 2).

Previously published data obtained in anesthetized, paralyzed patients were transformed with the following results: median extension of 6.6° at the Oc–C1 junction, 4.8° at C1–2, 3.2° at C2–3, 2.8° at C3–4, and 2.9° at C4–5. When compared at each cervical level and stage of intubation, no statistical difference was found for the results obtained in the cadavers.

Effect of Stabilization Maneuvers on the Intact Spine

Manual in-line cervical immobilization did not significantly limit motion at any measured level (Table 1). Traction limited overall Oc–C1 motion, reducing the median value of greatest segmental angular motion (8.8 to 4.9°, $p < 0.05$) (Fig. 3 *left*), but did not significantly affect motion at other levels (Table 1). While neither immobilization nor traction significantly reduced motion at C4–5, traction did change the predominant direction of motion from extension to flexion (Fig. 3 *right*).

Motion of the Injured Cadaveric Cervical Spine

In the presence of a posterior ligamentous C4–5 injury, the predominant direction of motion was flexion at C4–5 and extension at all other levels during direct laryngoscopy and orotracheal intubation (Fig. 4). The greatest degree of motion occurred at the Oc–C1 junction followed by that at the C1–2 junction, with less motion at C2–3 and

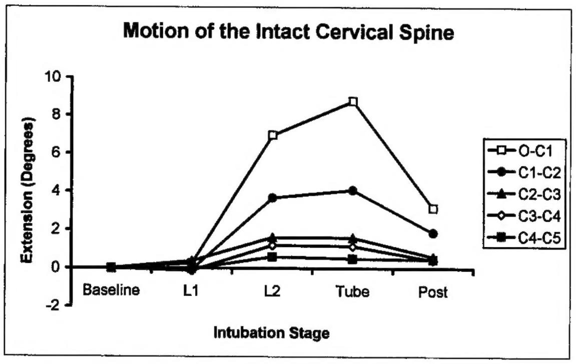

FIG. 2. Line graph showing a comparison of median values of segmental motion experienced by the intact cervical spine without stabilization during each stage of intubation for all levels measured. Positive numbers represent degrees of extension and negative numbers represent degrees of flexion. O–C1 = Oc–C1.

TABLE 1

*Median absolute values of greatest segmental angular motion obtained in the intact and injured spine**

Level	No Stabilization	Immobilization	Traction
intact spine			
Oc–C1	8.8	9.3	4.9†
C1–2	4.1	4.1	3.5
C2–3	1.8	2.2	1.7
C3–4	1.9	2.4	1.9
C4–5	2.1	1.9	1.2
injured spine			
Oc–C1	7.3	6.8	5.3†
C1–2	4.5	3.1	3.3
C2–3	1.6	1.7	1.7
C3–4	2.0	1.7	1.6
C4–5	1.8	2.8	2.2

* Values are presented in degrees.

† Indicates a statistically significant difference from that obtained in cases without stabilization ($p < 0.05$).

C3–4, which were practically indistinguishable. The degree of motion at C4–5 continued to be among the smallest of all measured levels.

Effect of Stabilization Maneuvers on the Injured Spine

Each stabilization maneuver produced the same effects on the Oc–C1 junction in the presence of the C4–5 injury and in the intact condition. Traction reduced motion (7.3 to 5.3°, $p < 0.05$; Table 1), whereas immobilization produced no significant effect. Neither manual in-line cervical immobilization nor traction reduced motion at C4–5 in the presence of the posterior ligamentous injury (Fig. 5).

Discussion

Motion of the injured cervical spine during orotracheal intubation is poorly understood. The major limitation to studying this problem is the risk of injury to living patients through excessive manipulation. Another limitation is the wide spectrum of traumatic cervical injuries, which does not allow a direct comparison between a sufficiently large group of patients with comparable and well-defined lesions. In this study, the C4–5 level was chosen as a representative subaxial level to evaluate the effects of instability and stabilization on cervical spine motion. Although C4–5 is not the most commonly injured level, it is the low-

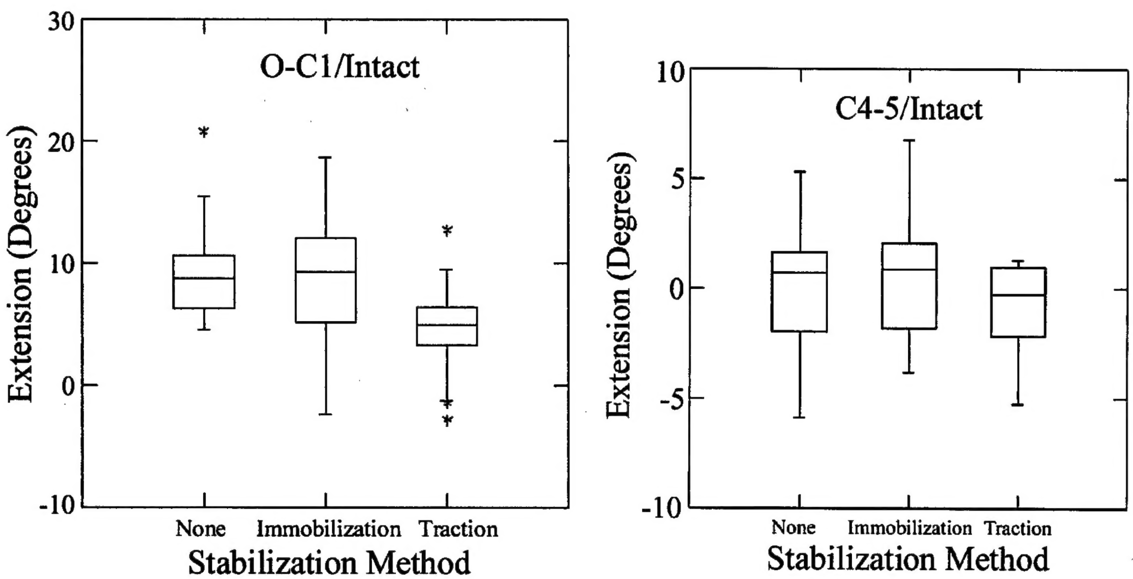

FIG. 3. *Left:* Box and whisker plot displaying comparison of uninjured Oc–C1 motion data with no stabilization, with immobilization, and with traction. *Right:* Box and whisker plot displaying comparison of uninjured C4–5 motion data with no stabilization, with immobilization, and with traction. *Left* and *Right:* The *outer hinges* of the box represent the 25th and 75th percentiles, with the *intersecting line* representing the median for that population. The *whiskers* represent the range of data extending beyond the hinges up to 1.5 times the difference between the median and each respective hinge. *Symbols* outside the whiskers represent outliers. Positive numbers denote extension and negative numbers denote flexion.

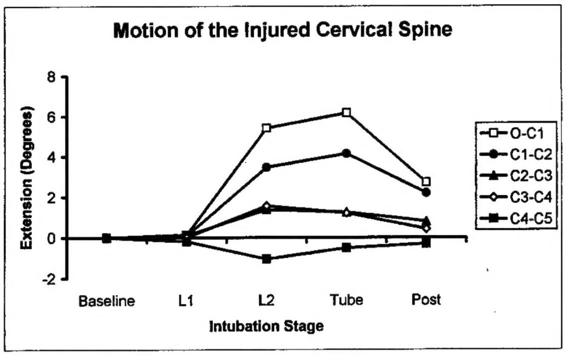

FIG. 4. Line graph showing a comparison of median values of segmental motion experienced by the cervical spine with a posterior ligamentous C4–5 injury without stabilization during each stage of intubation for all levels measured. Positive numbers represent degrees of extension and negative numbers represent degrees of flexion.

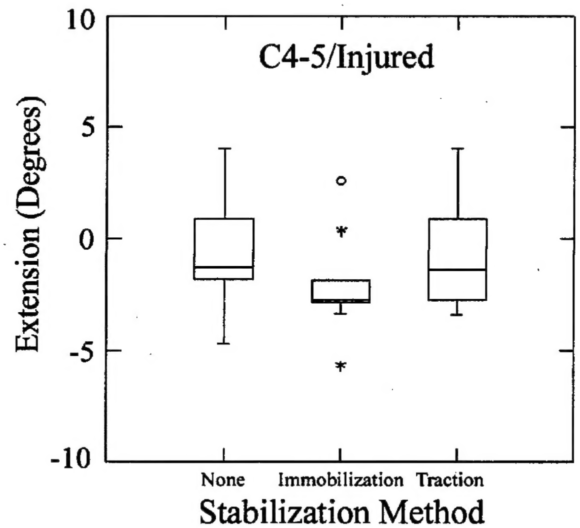

FIG. 5. Box and whisker plot displaying comparison of injured C4–5 motion data with no stabilization, with immobilization, and with traction. The *outer hinges* of the box represent the 25th and 75th percentiles, with the *intersecting line* representing the median for that population. The *whiskers* represent the range of data extending beyond the hinges up to 1.5 times the difference between the median and each respective hinge. *Symbols* outside the whiskers represent outliers. Positive numbers denote extension and negative numbers denote flexion.

est level that can be consistently visualized using video fluoroscopy. The purpose of this study was to establish a cadaveric model for evaluating cervical spinal motion in both the intact, as well as the injured, states.

To validate the cadaveric model as one accurately reflecting motion of living patients, previously published data obtained in anesthetized, pharmacologically paralyzed patients were compared with values of cadaveric motion obtained in this study.[15] No statistical difference could be found among intact spines in these groups in which stabilization measures were not undertaken.

In two previous reports the authors have evaluated the effect of stabilization maneuvers on uninjured cervical motion during direct laryngoscopy and orotracheal intubation. Hastings and Wood[11] have reported that manual inline immobilization reduced head extension during direct laryngoscopy and orotracheal intubation, whereas traction had no significant effect. Multiple differences in techniques used make difficult a direct comparison of our results with those obtained by Hastings and Wood. The angle finder measurements described most closely reflect motion of the head, not atlantooccipital motion. Hastings and Wood also intubated at "best view" of the larynx, whereas the minimal view was used in our study. The method of traction performed in our study (Gardner–Wells tongs) was also different from that performed in their study, and the force of traction undertaken by Hastings and Wood was not measured. All of these factors may account for the disparate results.

Majernick, et al.,[14] have measured cervical motion during direct laryngoscopy and orotracheal intubation by using two static radiographs: baseline and vocal cord view. Intervertebral angular changes were not measured; instead, these investigators used the combination of two parameters termed "$\Delta C_{1\text{-}0}$" and "$\Delta C1+C5$" for comparison of cervical motion without stabilization and with manual in-line immobilization. The value $\Delta C_{1\text{-}0}$ was the change in the distance between the inferior "spinous process" of C-1 and the occiput and represented the degree of extension at the Oc–C1 joint. The value $\Delta C1+C5$ represented the summation of changes in the anterior–posterior distance of C-1 and C-5 measured when C-3 was superimposed on the radiographs. They reported that immobilization reduced cervical motion. The different methods of measuring cervical motion and the small number of unpaired subjects used for comparison (four) may account for the differences in results between our study and that of Majernick and colleagues.

Several investigators have examined the effects of differing intubation techniques and stabilization maneuvers on spinal motion in cadavers with unstable cervical injuries. Bivins, et al.,[3] have reported that traction during orotracheal intubation reduced subluxation, but caused significant distraction of unstable cervical injuries. Their study was limited by its small number of subjects (four) and its potential inconsistency in the force applied and the view obtained during intubation. Although there is predictably some distraction that occurs with axial traction, these investigators did not study the effects of different traction weights. At 6.8-kg traction, they used 50 to 100% more weight than we advocate based on our current study. In their study protocol there was also a 15-kg force applied caudal to the shoulders with an arm-traction device to facilitate visualization of the lower cervical spine. It is unclear what effect this might have had on spinal motion. Last, the injuries included in their study (one C6–7 fracture/dislocation, one hangman's fracture, and two Oc–C1 dislocations) are more severe and thus poorly comparable to our C4–5 posterior ligamentous injury.

In a cadaver study in which they used a video fluoroscopy technique similar to ours, Donaldson, et al.,[6] have compared oral and nasal intubation techniques before and after a surgically created posterior ligamentous injury at

C5–6.[6] They reported that nasotracheal intubation caused less translation (0.39 mm compared with 1.23 mm, respectively) and less distraction (0.67 mm compared with 2.29 mm, respectively), but more angulation (4.76 compared with 3.90 mm, respectively) than orotracheal intubation at the destabilized level when comparing the pre- and postinjury spines. They also pointed out that preintubation airway maneuvers such as cricoid pressure, jaw thrust, and chin lift could cause as much motion as the intubation procedure itself. Their conclusions are weakened, however, by the fact that they did not apply statistical analyses to any of their findings.

Aprahamian, et al.,[2] have reported, based on the evaluation of one cadaver, widening of the injured disc space during orotracheal intubation in the presence of a complete C5–6 injury, but no change in subluxation when compared with baseline x-ray films. They found an increase in posterior subluxation (≥ 5 mm) during blind nasotracheal intubation, especially when pressure was applied to the anterior neck during the procedure; however, these changes were determined by comparing measurements obtained on static radiographs before and at the completion of each maneuver. There was no assessment of the dynamic changes occurring during the procedures when the majority of motion takes place.

In the present study, although limited in its scope to only posterior ligamentous C4–5 injury, we systematically evaluated the effect of commonly used stabilization techniques on segmental cervical motion in the presence of a well-defined injury. The amount of motion necessary to cause a neurological deficit is not known, but neither traction nor manual in-line cervical immobilization significantly reduced the motion produced by direct laryngoscopy and orotracheal intubation at the destabilized segment.

Conclusions

Cervical motion measured in fresh cadavers during orotracheal intubation accurately reflects that of living patients. Little motion occurs at C4–5 during direct laryngoscopy and orotracheal intubation in either the intact or posteriorly injured states, and neither manual in-line cervical immobilization nor traction has a significant effect on motion at C4–5 under these conditions. However, because the extent of injury is often unclear, especially in an emergency situation, it is still recommended that an attempt at stabilization be considered. Further work evaluating motion of the completely destabilized subaxial spine as well as the craniovertebral junction is underway. The information generated from these studies may lead to further recommendations. Detailed knowledge of segmental motion of the injured cervical spine during direct laryngoscopy and orotracheal intubation should help caregivers in critical decision making when an emergency airway is required in a patient with a suspected or known cervical injury.

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Disclaimer

The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as an official Department of the Army position or decision unless so designated by other documentation.

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